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PILOT ABILITY TO UNDERSTAND SYNTHETIC VOICE
AND RADIO VOICE WHEN RECEIVED SIMULTANEOUSLY

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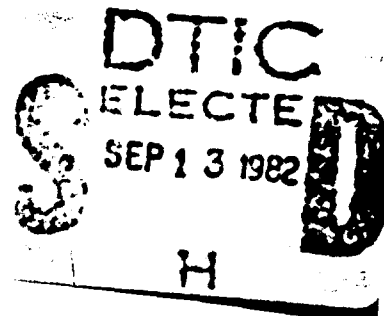
ELLIOTT MANAKER
SENIOR HUMAN FACTORS ENGINEER
SYSTEM ENGINEERING DEPARTMENT
GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

REPORT NO. ACT-R-82-01, June 1982

Advanced Development Project 168-101

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ABSTRACT

PILOT ABILITY TO UNDERSTAND SYNTHETIC VOICE AND RADIO VOICE WHEN RECEIVED SIMULTANEOUSLY

A prior study of the use of a voice synthesis system and its implementation in the F-14 aircraft was completed by Grumman Aerospace Corporation in 1981 for the U.S. Naval Air Development Center. The goals of that study were to determine if synthetic voice messages would reduce the pilot's workload, increase his effectiveness during the mission, and to establish the hardware impact on the aircraft. Recommendations for additional studies to use voice in the F-14 and other future naval aircraft were made as well as for investigations into related areas such as crew perception and discrimination of a computer generated voice.

Some pertinent questions arising from the F-14 study concerned: a, the distinctiveness and intelligibility of a computer generated synthetic voice in the aircraft hearing situation; b, whether or not the pilot can separate radio-transmitted human voice messages of interest from simultaneously generated synthetic voice messages; and c, the optimum method of presenting such messages through the headset.

An exploratory study was designed to investigate these questions. The intent was to examine differing methodologies in presenting the stimuli used, and to ascertain trends in the subjects performance data.

Results tend to support the belief that synthetic voice messages provide an effective means of presenting alerting messages and data to a pilot. Radio voice does not interfere appreciably with reception of synthetic voice.

Use of a dichotic listening method may enhance perception and understanding of radio voice messages when received simultaneously with synthetic voice messages.

Future studies will use these data to establish definitive design recommendations for incorporation of synthetic voice in aircraft.

PILOT ABILITY TO UNDERSTAND SYNTHETIC VOICE AND RADIO VOICE WHEN RECEIVED SIMULTANEOUSLY

I. BACKGROUND

A prior study of the use of a voice synthesis system and its implementation in the F-14 aircraft was completed by Grumman Aerospace Corporation in 1981 for the U.S. Naval Air Development Center. The goals of that study were to determine if synthetic voice messages would reduce the pilot's workload, increase his effectiveness during the mission, and to establish the hardware impact on the aircraft. Recommendations for additional studies to use voice in the F-14 and other future naval aircraft were made as well as for investigations into related areas such as crew perception and discrimination of a computer generated voice.

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An exploratory study was designed to investigate these questions. The intent was to examine differing methodologies in presenting the stimuli used, and to ascertain trends in the subjects performance data.

Future studies will use these data to establish definitive design recommendations for incorporation of synthetic voice in aircraft.

II PROBLEM

A crew workload problem exists in today's tactical military aircraft which appears to contribute to mission failure and/or loss of crew and aircraft. Investigations point to crew overloading during critical mission phases, primarily in the visual sensory channel.

Much effort has been expended to ease crew task loading. Individual control/display developments, such as the head-up display or the multi-function display, are only partial solutions since they have not reduced the amount of information input to the crew, and have generated new problems. These problems result in maintaining a high loading on crew visual and motor sensory channels.

An alternative method of crew/system interaction is needed. This method must unburden the crew's visual and motor information channels (i.e. free eyes and hands for other tasks); it must not disrupt attention; it must allow quicker assessment of situations and faster decision making, which in the military can mean the difference between life and death and the conservation or loss of expensive equipment.

There is general agreement in the literature that performance is enhanced by moving some of the crew's information input from the visual channel to the auditory channel. It is reasonable to assume that the use of a voice mode should be equal to or more accurate than current information presentation methods, and should allow the crew greater freedom to perform other tasks. By using the auditory sense to perceive part of the information load, eyes and hands can be diverted to accommodate other inputs.

A synthetic voice capability to alert the flight crew to cautions and warnings has been used in both the F-18 and the F-15 aircraft. Preliminary information tends to support the contention of enhanced crew performance under high work-load conditions.

Unquestionably, today's voice generation/computer technology allows the use of speech display in the cockpit. Equipment is available for the generation of several types of speech, e.g., female voice, male voice and mechanical or robotic sounding voice. A synthetic female voice has been chosen for use in both the F-18 and F-15 aircraft, but experimental data supporting this decision is lacking. (Some studies mention that a few pilots question the use of a female voice).

When the synthetic voice is transmitted to the F-18 and F-15 pilots through the intercom, radio reception is muted to the degree that essentially it is turned off. This method precludes the simultaneous reception of a potentially important radio message, as for example, during air combat. The major investigation of this study is whether or not the synthetic voice message and the radio message can be perceived and understood when presented simultaneously.

A literature search yielded no studies on the discrimination and relative intelligibility between competing synthetic and human voice messages. The bulk of related studies on hearing simultaneous or overlapping messages were performed between the early 1950's and the mid-1960's. It was hoped that methods could be discovered which would alleviate or mitigate the confusion which occurs when attempting to listen to and respond to simultaneous or overlapping message transmissions. These past experiments investigated various aspects of listening, understanding and responding to one or more of a number of simultaneously received messages. However, they did not address the use of synthetic voice, did not consider the cockpit environment, did not deal with short messages within a finite set, and in most cases used naive subjects.

Some results of these experiments, however, are applicable directly to the problem of discriminating two simultaneously spoken messages:

1. Each voice should have different qualities, i.e., pitch, speed, male/ female, accent, intensity level.
2. Each voice should originate from an apparent different direction.
3. Each voice should involve differing syntax and deal with different subject matter.
4. The listener should be trained and experienced in the use of pertinent message vocabulary, syntax and context.

For our application, item 1 is a given in that major differences do exist between synthetic speech and human speech. These differences can be enhanced further by equipment design, selection of voice type and by the perceivable difference in quality between radio and intercom.

Item 2 can be implemented in the cockpit. However, investigation is required to determine if competing messages can be perceived with intelligibility. Another facet of this question is how the simultaneously received messages (synthetic voice and human voice) should be presented to the crew. The manner in which these messages are presented through the headset will impact perception and intelligibility, e.g., both messages to both ears, each message to separate ears, etc.

Item 3 also is implemented easily since the inherent differences in use requirements between radio and synthetic speech generation equipment involve differing syntax and subject matter.

Item 4 will be an inevitable part of a pilot's training.

Further examination of the literature indicated that some recent (1970's) investigations have studied individual word intelligibility under stressful flying conditions and the relative alerting capability between tones and words (taking into account semantic context). However, discrimination and relative intelligibility between competing synthetic and human voice messages apparently still have not been examined.

III OBJECTIVE

This experiment was designed to:

1. Determine the capability to recognize and understand computer generated female voice messages in the presence of human male voice radio messages.
2. Determine the capability to recognize and understand human male voice radio messages of interest and computer generated female voice messages when presented simultaneously.
3. Evaluate the effect of listening method on message discrimination and intelligibility.
4. Evaluate the methodology used in this study.
5. Suggest further questions for investigation.

IV APPROACH

A. General

Six subjects, all experienced flyers, performed an aircraft tracking task while listening to audio tapes of typical air traffic control (ATC) radio messages and a synthetic female voice enunciating cautions and warnings. Caution and warning messages were selected for the synthetic voice messages since they appear obvious candidates for cockpit applications. The F-18 and F-15 aircraft have synthetic voice for caution and warning messages in flight test aircraft. The same application was recently studied for use in the Grumman F-14 aircraft.

B. Tracking Task

The tracking task was performed by the subject as a symbolic representation of flying an airplane. A horizon line and aircraft symbol were displayed on the CRT. The force stick controller commanded aircraft symbol movement. The computer was programmed to move the aircraft symbol in such a manner that the subject had to continually manipulate the control to maintain level flight. Information was presented to the subject on a CRT to simulate a flying task. The words ELEV and ANGLE appeared whenever the subject allowed the aircraft symbol to shift 1/8" above or below the horizon line and/or to deviate by $\pm 3^\circ$ in roll from the horizontal. These data simulated the information a pilot gathers from his flight instrumentation during flight. The graphic image simulated his attitude indicator (Figure 1). Aircraft control was maintained with a force stick hand controller.

The computer stored the following data which was printed out after each run: a, distance and angle off-track; b, on-track time; c, off-track time; and d, cumulative total of off-track occurrences.

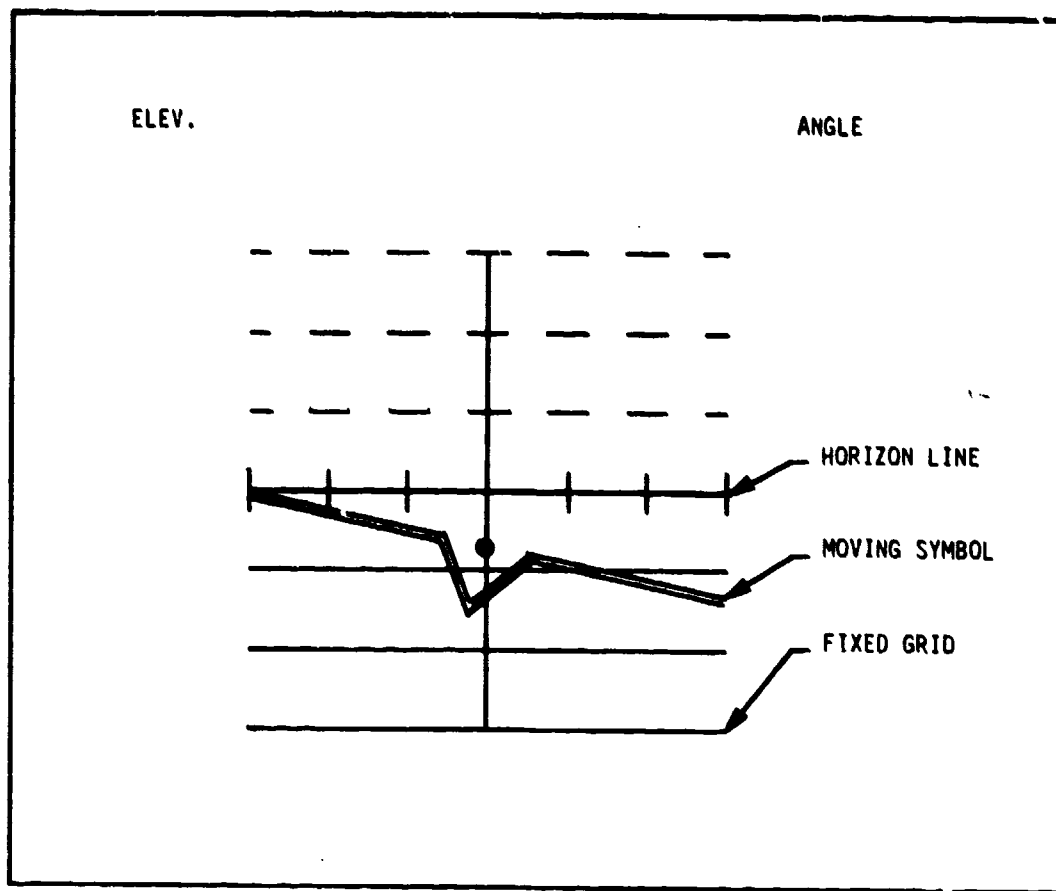


FIGURE 1: TRACKING TASK CRT DISPLAY

C. Experiment Description

Each subject was requested to attend to radio messages preceded by his assigned call sign and to repeat them out loud while performing the tracking task. The subjects also were requested to attend to all caution and warning messages and repeat them out loud. Further, they were told that radio messages and caution and warning messages could be presented simultaneously, and that they should repeat both. The subjects were instructed that, at the very least, they should state aloud the sense of what was understood if they could not repeat the messages verbatim.

Three radio messages with the subject's call sign preceding the message and four caution and warning messages were presented on each of the three experiment runs.

It was emphasized that the aircraft attitude and altitude must be maintained at all times.

All verbal responses were recorded.

Each subject performed the tracking task and was presented with messages to repeat three separate times. He was not informed about the different methods of message presentation. Each session was characterized by a different method of message presentation through the earphones:

Method I: DIOTIC - Radio messages and caution and warning messages were presented to both ears simultaneously.

Method II: DIOTIC/DICHOTIC - The cautions and warnings were presented to one ear while the radio messages were presented to both ears.

Method III: DICHOTIC - Radio messages were presented to both ears. During simultaneous transmission of the radio message and the caution and warning message, the radio message was blanked in the ear receiving the caution and warning message.

Figure 2 depicts these conditions. Table 1 presents the matrix of conditions used in the study. It should be noted that the presentation order to the subjects of the three message conditions was counterbalanced. This ordering precludes carryover effects that might occur from one experiment run to another, thereby influencing a subject's performance.

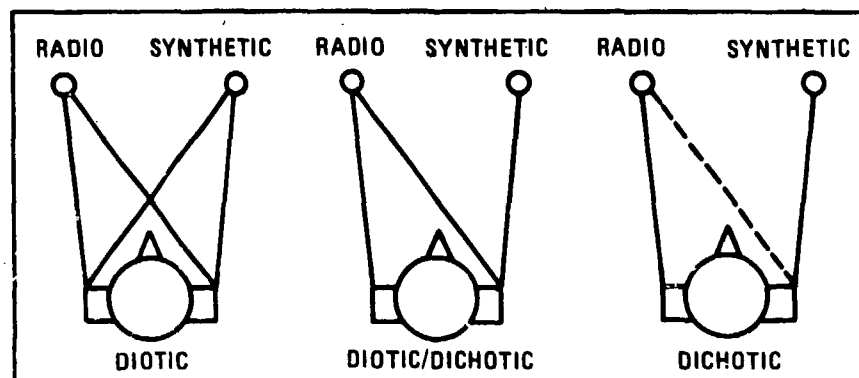


FIGURE 2: LISTENING METHODS. The manner of presenting simultaneously received synthetic and human voices through the headphones

TABLE 1: STUDY MATRIX*

LISTENING METHOD	RADIO MESSAGES						SYNTHETIC MESSAGES							
		SUBJECT							SUBJECT					
		A	B	C	D	E	F		A	B	C	D	E	F
DIOTIC	1							1						
	2							2						
	3							3						
	4							4						
		BOTH EARS							BOTH EARS SUPERIMPOSED					
<u>DIOTIC</u> DICHOTIC	4							5						
	5							6						
	6							7						
								8						
		BOTH EARS							ONE EAR SUPERIMPOSED					
DICHOTIC	7							9						
	8							10						
	9							11						
								12						
		BOTH EARS							ONE EAR RADIO BLANKED					

* As shown, in some cases messages were presented alone, that is, without overlap or synchrony with the other type - radio vs. synthetic or synthetic vs. radio. This was to allow for the determination of the subject's perception without the masking or confusing possibility presented when messages are received simultaneously.

V. APPARATUS

The study was performed in the Grumman Plant 14 Advanced Cockpit Technology Lab (ACTL). A CRT display and force stick hand controller were used for a tracking task designed to preclude the subject from concentrating solely on his listening task. The Lab's Varian 76 computer was programmed to provide a fixed horizon and moving aircraft symbol on the Sanders ADDS 900 Graphics System CRT which the subject commanded via the force stick control.

Audio cassette tapes were played-back on two JVC DD-5J stereo cassette decks. Both subject and experimenter listened to the tapes through Panasonic/Technics EAH-810 stereo headsets. The subject's voice was picked up by a microphone for the recording of his responses on a portable cassette recorder. The subject's headset and microphone were plugged into a junction box. The experimenter's headset was plugged into a specially designed audio mixer which controlled the routing of the taped messages to the subject via the junction box and directly to the experimenter (Figure 3). The experiment set-up is shown in Figures 4, 5 and 6.

VI VOICE STIMULI TAPES

A. Generation of Radio Messages

Air Traffic Control (ATC) radio messages were obtained by setting up a radio receiver tuned to local air space frequencies, tying in a voice operated circuit and recording enough messages to fill up an audio cassette with more than eight hours of messages compressed into one hour of tape. A sufficient number of messages with a particular call sign were gleaned from this tape for use in the experiment.

Selected, reasonably intelligible, messages were chosen from this source tape for replay to the subject. Messages which did not require a response by the subject were interspersed among those messages of interest which required the subject to respond. Silent periods as well as un-intelligible voices also were used between intelligible voices to simulate air traffic control and in-flight communications.

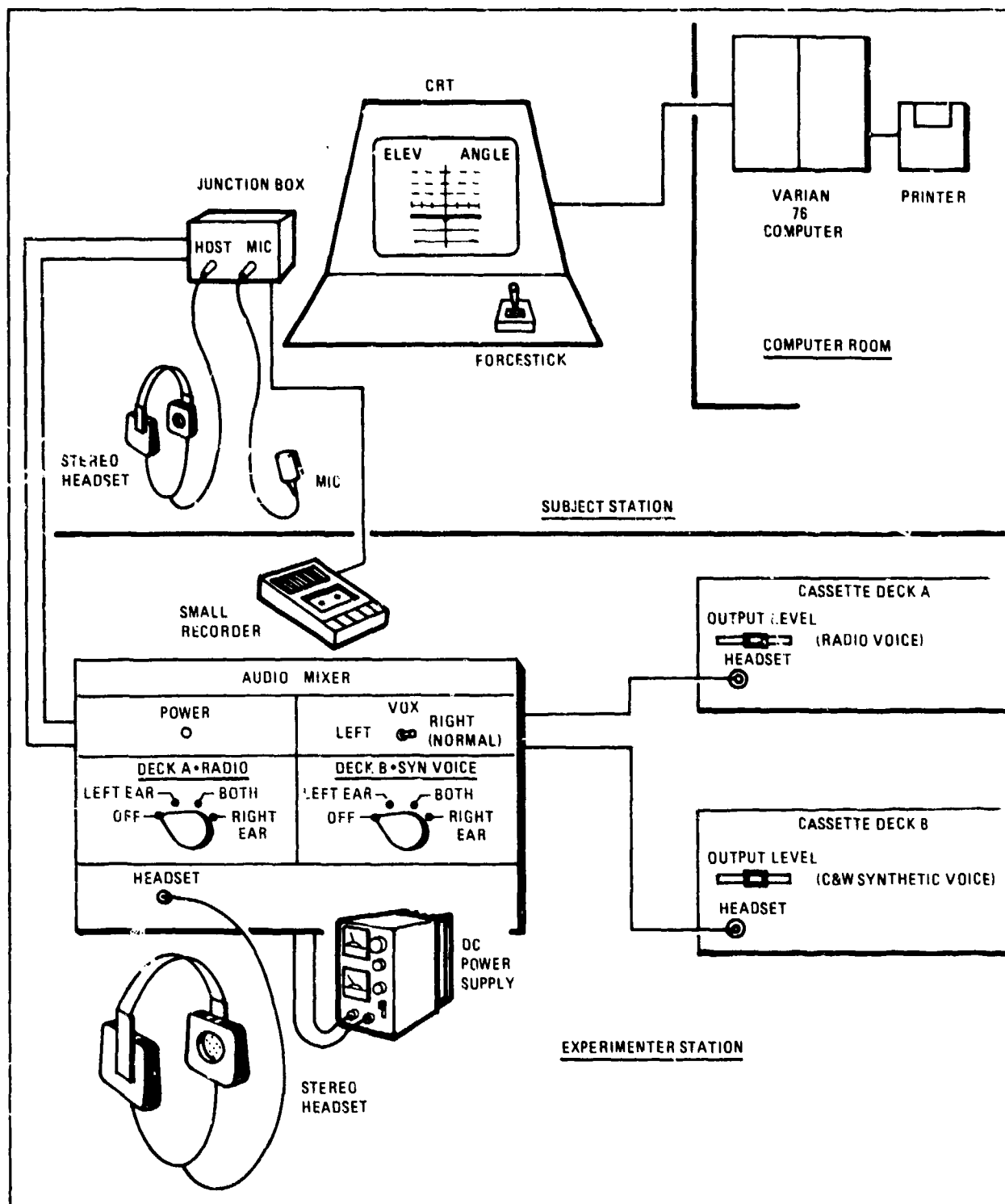


FIGURE 3: APPARATUS CONFIGURATION

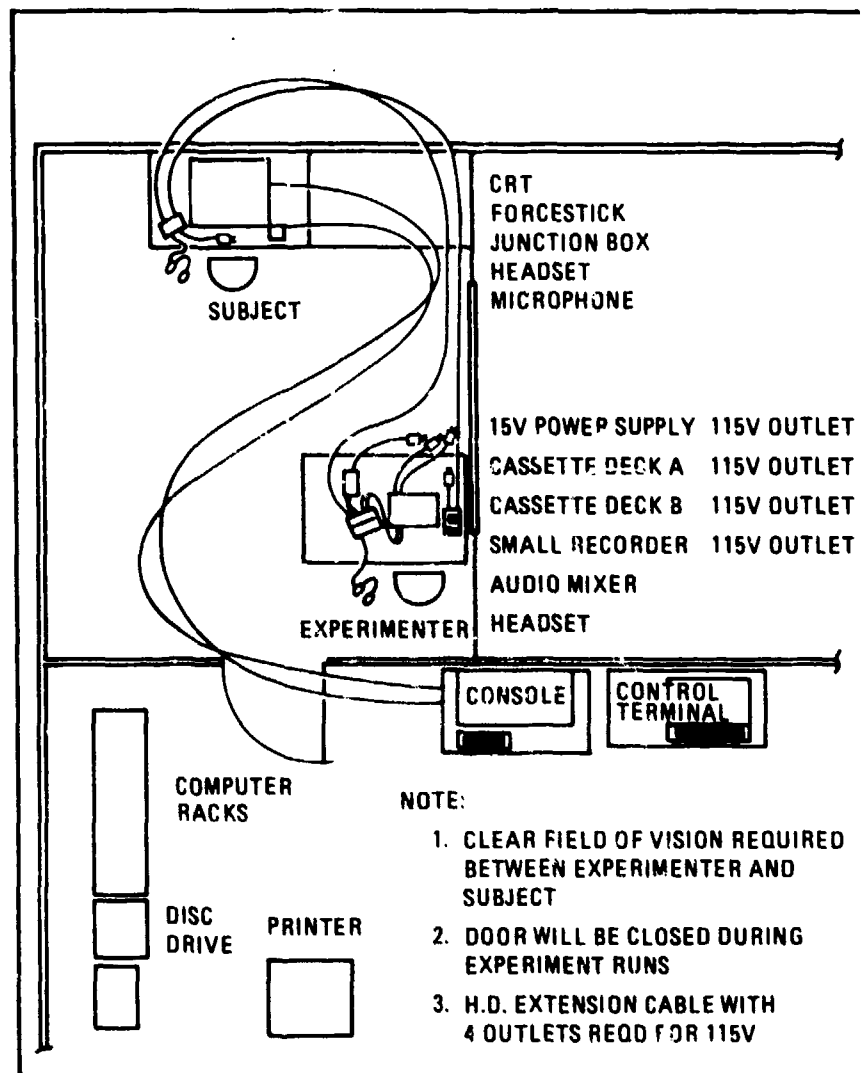


FIGURE 4: ACTL EXPERIMENT ROOM CONFIGURED FOR STUDY

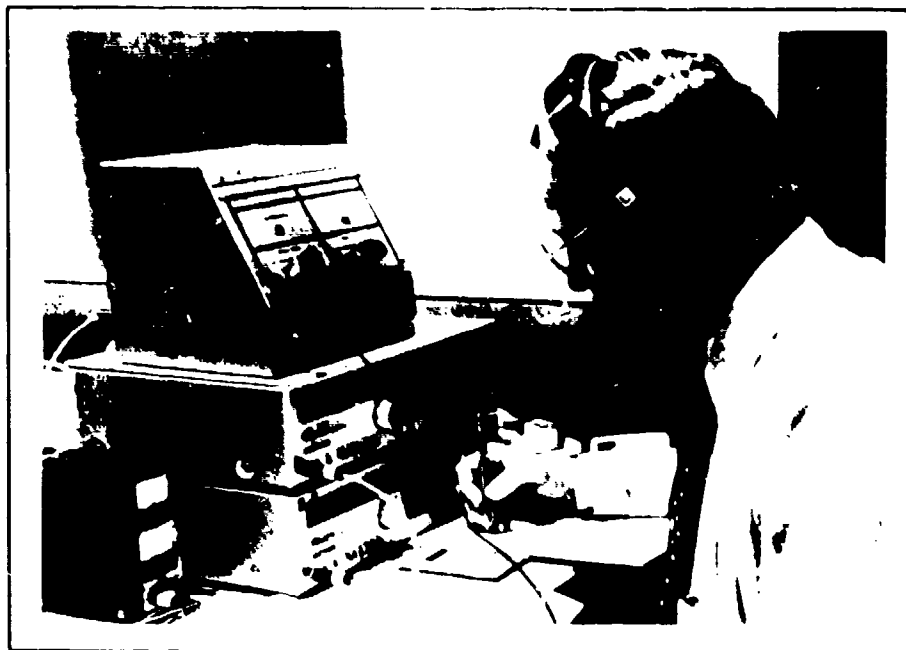


FIGURE 5: VIEW OF EXPERIMENTER'S STATION.



FIGURE 6: VIEW OF TEST SUBJECT'S STATION.

B. Generation of Synthetic Voice Messages

A tape was obtained from a manufacturer of synthetic voice apparatus. This tape contained the set of caution and warning messages tailored for the F-14 aircraft. These messages were re-recorded for re-play in synchrony with the radio messages.

C. Tapes Used In Study

Three tapes were produced using the source ATC radio communication tape, one tape for each listening method. Since nine messages were required and six were available, three were used twice each. Similarly, three tapes using selected synthetic voice messages were produced from the single vendor's tape. Twelve different messages were chosen from a total of fifteen available. The tapes chosen for use during the DICHOTIC condition (both radio and synthetic voices) were combined into one tape for replay to the subject. Since it was not feasible to use an actual voice operated circuit to interrupt the radio voice in one ear, a reel-to-reel recorder was used which allowed separate recording on each of two tracks. The radio messages were recorded on both tracks of a reel-to-reel tape, then the synthetic voice messages were interjected at the appropriate points on one of the two tracks. This recording was transferred to a single cassette for use in the study.

1. Audio Levels of Radio Messages and Synthetic Voice Cautions and Warnings

As previously stated, source tapes were re-transcribed on cassettes for use in the experiment. Since the ATC radio messages varied in audio level depending upon the distance and power levels of the original source, a subjective evaluation was made during the re-taping to equalize the audio levels of all radio messages of interest.

Similarly, a subjective evaluation was made on the synthetic voice caution and warning (C&W) messages to equalize their levels with the radio levels. However, since the caution and warning messages were not radio-transmitted, but generated by a computer and directly recorded, they sounded stronger even at audio level settings which equaled the radio settings. This is attributed to a greater signal-to-noise (S/N) ratio

inherent in the method of generation. Discussions with pilots before the experiment and the subjects after the experiment verified that this difference in audio levels between radio and synthetic voice caution and warning compares with the difference in audio levels between radio and intercom in an aircraft. It appears then that the audibility levels of the synthetic voice messages and the radio voice messages were reasonably reproduced in the study.

VII TEST SUBJECTS

Six test subjects were randomly selected from a population of experienced pilots in the employ of the Grumman Aerospace Corporation. These employees hold current pilots licenses and/or have military flying experience. They passed an audiometric screening performed by the Grumman Medical Department.

VIII PROCEDURE

Each subject was tested individually to preclude discussion of the study procedure with the other subjects. Each received a pre-test briefing. Written instructions were given to the subjects to ensure that each received identical directions. See Appendix, page 30. Each subject received a familiarization run to become acquainted with the tracking task and messages to be received. He also practiced responding to the messages. During the familiarization run, both radio and synthetic voice messages were presented separately (not simultaneously) and to both ears (diotically). The radio messages presented were typical ATC conversations which included the same messages to be received during the experiment. The synthetic voice and the synthetic caution and warning messages also were the same as used during the experiment. A list of these synthetic voice messages was given to each subject during the familiarization period. The rationale for providing this message list was that a pilot who flies a military aircraft incorporating a synthetic voice caution and warning system, through intensive training, will be intimately familiar with the limited vocabulary and the voice itself. Conversely, a pilot does not know precisely what he will hear over the radio.

The familiarization run was complete when the subject had listened to the message tape at least once and was satisfied with his handling of the force stick controller.

Each subject experienced three separate experiment runs. As earlier indicated, each run was characterized by a different manner of auditory presentation of the radio and synthetic voice messages to the subject's ears. Table 2 presents the randomized order of presentation of these messages.

After completion of all three runs for each subject, a debriefing between experimenter and subject was held. First, a questionnaire was completed by the subject to elicit his subjective evaluations of the quality of both the synthetic voice and the radio voice. A copy of the questionnaire appears in the Appendix on pages 31 and 32. Then, a free-ranging discussion was held covering the questionnaire and the subject's comments, opinions and suggestions concerning airborne voice communications based on his flight experience.

IX PERFORMANCE MEASURES

The subject was required to repeat each message aloud when he perceived a "message of interest". Messages of interest are defined as: a, all synthetic voice messages; and b, all radio messages preceded by the key call sign "94 WHISKEY". Scoring was performed by the experimenter listening to the subject and determining if the message was repeated or responded to correctly at the right time. The subject's verbal response was recorded for later verification and evaluation.

X RESULTS

A. Performance Indices

Test subject response data were collected to indicate perception and understanding of the audio stimuli presented in each of the three listening methods. These data are presented in the form of performance indices. The indices, expressed as percentages, have been converted from ratios derived from the series of test subject responses collected during the experiment. They are used as measures of the test subject's ability to perceive and understand both radio and synthetic voice messages.

TABLE 2: PRESENTATION ORDER OF EXPERIMENTAL CONDITIONS
FOR SIX SUBJECTS

SUBJECTS	SEQUENCE OF CONDITIONS	LEGEND
A	1-2-3	1 DIOTIC
B	1-3-2	2 DIOTIC/DICHOTIC
C	2-3-1	3 DICHOTIC
D	2-1-3	
E	3-1-2	
F	3-2-1	

Responses were collected in three categories: a, perceived and understood; b, perceived but not understood; and c, not perceived (therefore not possible to understand).

To enable quantification of the data, numerical scores were assigned to the collected responses, thusly:

Message perceived and understood	=	10 points
Message perceived but not understood	=	5 points
Message not perceived	=	0 points

The performance index, expressed as a percentage, was derived by dividing the actual score by the possible total score. For example, out of a total of six messages transmitted, if three messages were understood, two messages not perceived, and one message perceived but not understood, scoring would be 10 + 10 + 10 + 0 + 0 + 5 respectively. The actual score then, would be expressed as 35/60. The denominator 60 results from the total number of six transmitted messages times 10 (total possible score). Conversion to a percentage gives an index of 58.3%.

B. Tracking Task

Since the tracking task was used only to keep the subject busy so he would not concentrate on listening for the audio messages, an in-depth analysis of the computerized tracking data was not performed. However, a perusal of these data indicated no apparent decrement in performance during the periods when the subject's attention was shared with pertinent radio and/or caution and warning messages.

C. Effects of Listening Methods

The raw response data were converted to numerical scores as shown in Figure 7. Inspection of the data for listening methods indicates that synthetic voice caution and warning messages generally produced a much higher percentage of correct responses than did radio messages. This result is not suprising since the quality of the synthetic voice messages is significantly better than typical aircraft radio messages.

A. RADIO MESSAGE DATA					
LISTENING METHOD	MESSAGES				SCORES
	A	B	C	D E F	
DIOTIC	1	10	10	10 10 10	60/60
	2	0	0	0 0 0	0/60
	3	0	10	10 5 10 0	35/60
					95/180
<u>DIOTIC</u> DICHOTIC	4	0	10	10 10 10 10	50/60
	5	0	0	0 0 0 0	0/60
	6	10	10	10 10 10 10	60/60
					110/180
DICHOTIC	7	10	10	10 5 10 10	55/60
	8	0	0	0 0 10 5	15/60
	9	10	10	10 5 10 5	50/60
					120/180
					66.6%
B. SYNTHETIC VOICE MESSAGE DATA					
LISTENING METHOD	MESSAGES				SCORES
	A	B	C	D E F	
DIOTIC	1	10	10	10 10 10 10	60/60
	2	10	10	10 10 10 10	60/60
	3	5	10	10 10 10 10	55/60
	4	10	10	10 10 10 10	60/60
					235/240
<u>DIOTIC</u> DICHOTIC	5	10	10	10 10 10 10	60/60
	6	5	5	10 10 5 10	45/60
	7	5	10	10 10 10 10	55/60
	8	10	10	10 10 10 10	60/60
					220/240
DICHOTIC	9	10	10	10 10 0 5	45/60
	10	5	10	10 0 10 0	45/60
	11	10	10	10 10 10 10	60/60
	12	10	10	10 10 10 10	60/60
					210/240
					87.5%

FIGURE 7: PROCESSED DATA ON LISTENING PERFORMANCE

A review of the data for all radio messages (Figure 7A) compared with all synthetic voice caution and warning messages (Figure 7B), as plotted in Figure 8, shows only slight differences (between listening methods) in the percentage of correct responses of either radio messages or synthetic voice caution and warning messages. However, when the data are separated into categories of simultaneous reception of competing messages (Figure 9), and reception with no competition (Figure 10), large differences appear.

The data in Figure 9 show that the method of message presentation affects understanding. Apparently, the use of a dichotic method for presenting a caution and warning message will permit greater understanding of the radio message with only a slight detriment to the understanding of the synthetic voice message.

The data in Figure 10 show expected results. When either type of message is received with no simultaneous competition, it will be understood.

D. Effects of Masking the Radio Call Sign

It should be remembered that the subjects were instructed to respond only to radio messages that were preceded by a specific call sign. Therefore, any message not preceded by that call sign would be ignored. It is obvious that the perception of the call sign is vital to the subject's response. Thus, an analysis was performed on subject performance as affected by the degree of obfuscation of the radio message call sign by the synthetic voice message.

A review of Tables 3, 4 and 5 indicates the overlap of the caution and warning and radio messages when simultaneously presented to the subject.

Tables 6 and 7 show that where the call sign was presented from partially to fully obscured, more and more messages were missed. Obviously, the obscuring of the call sign by the synthetic voice messages, as had occurred in the study, could be a real-life situation. However, the probability of such occurrences are considered to be low. Therefore, it could be expected that a pilot would be capable of perceiving the majority of the radio messages directed to him.

LEGEND:  SYNTHETIC VOICE  RADIO VOICE

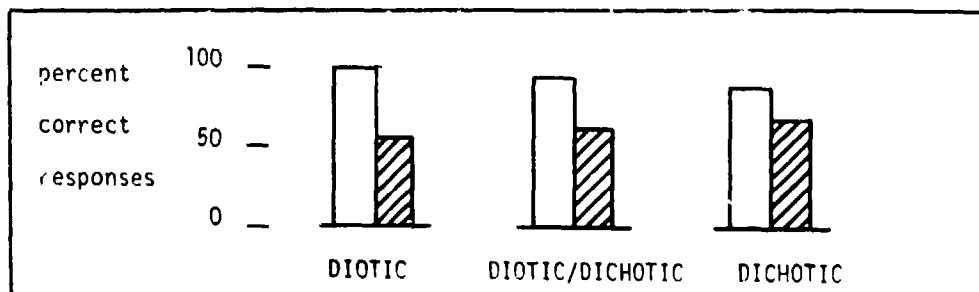


FIGURE 8. PERCENT CORRECT RESPONSES FOR EACH LISTENING METHOD.

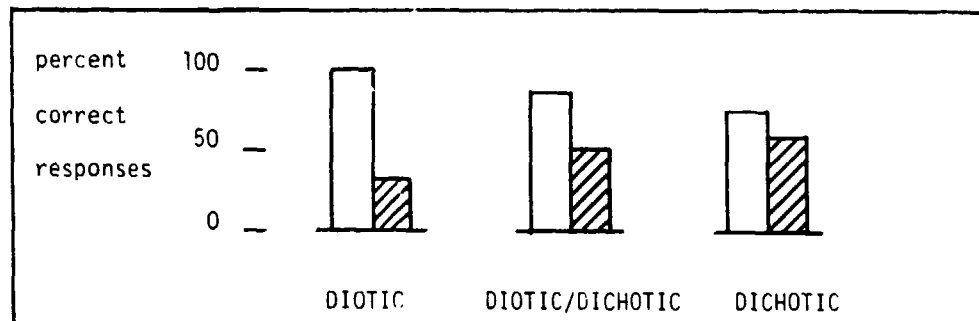


FIGURE 9. PERCENT CORRECT RESPONSES FOR KEY RADIO MESSAGES AND SYNTHETIC VOICE CAUTION AND WARNING MESSAGES DURING SIMULTANEOUS RECEPTION.

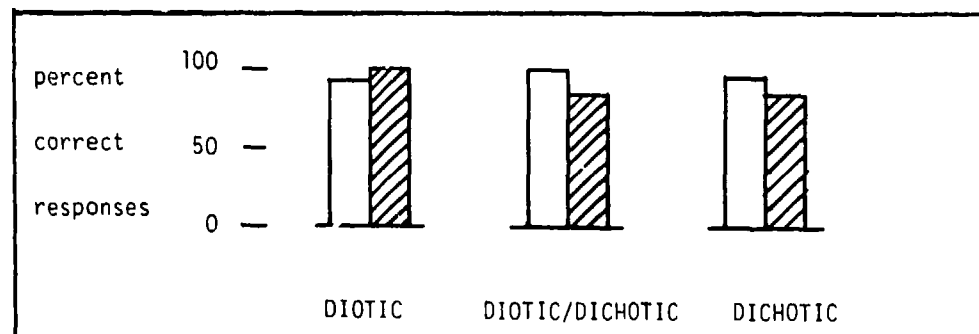
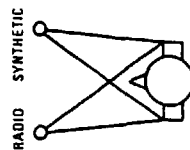
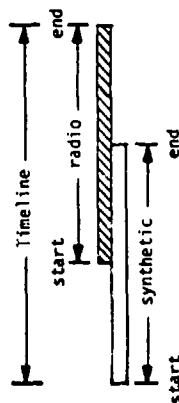


FIGURE 10. PERCENT CORRECT RESPONSES FOR KEY RADIO MESSAGES AND SYNTHETIC VOICE CAUTION AND WARNING MESSAGES WHEN RECEIVED INDIVIDUALLY WITH NO SIMULTANEOUS COMPETITION.

TABLE 3: ANNOTATED CHART SHOWING DEGREE OF MESSAGE SYNCHRONY: DIOTIC LISTENING

Degree of message overlap shown in time as follows:



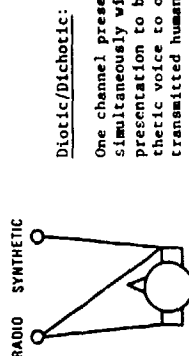
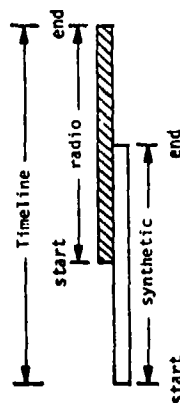
Diotic:

Two channels presented to both ears simultaneously. Synthetic voice on one channel and radio transmitted human voice on second channel.

MESSAGES PRESENTED TO SUBJECTS, SHOWING DEGREE OF OVERLAP	COMMENTARY	REMARKS
1. Nine four Whiskey: Traffic off your right side 1 o'clock below you 2000 land at Kennedy	1. Radio message presented alone. Perceived and understood by all subjects.	
2. Caution: Oil Pressure	2. Synthetic voice message presented with radio messages of no interest. Perceived and understood by all subjects.	
3. a. Caution: Bleed Duct Overheat Nine four Whiskey: Left two-two-zero b. Caution: Bleed Duct Overheat	3. Radio and synthetic voice messages presented as shown. Subjects A and B received a. Subjects C through F received b. Radio message missed by all subjects. Synthetic voice message understood by all subjects.	Where call sign overridden by CSW - all subjects missed radio message.
4. Warning: Wing Sweep Disabled	4. Synthetic voice message presented with radio messages of no interest. One subject perceived but didn't understand, all others understood message.	
5. Nine four Whiskey: Can proceed on course remain this frequency Caution: Bingo Fuel	5. Radio and synthetic voice messages presented as shown. Radio message missed by two subjects (A,F). Radio message perceived, not understood by one subject (D). Radio message understood by three subjects (B,C,E). Synthetic voice message understood by all subjects.	Call sign unobstructed. Those who missed radio may have lost memory of message when C&W intruded and competed for attention.

TABLE 4: ANNOTATED CHART SHOWING DEGREE OF MESSAGE SYNCHRONY: DIOTIC/DICHOTIC LISTENING

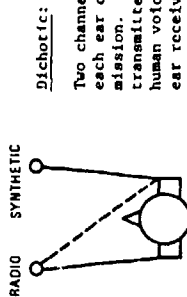
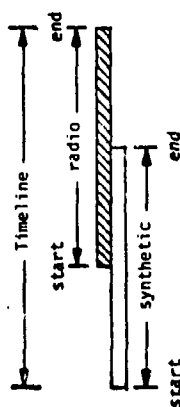
Degree of message overlap shown in time as follows:



MESSAGES PRESENTED TO SUBJECTS, SHOWING DEGREE OF OVERLAP	COMMENTARY	REMARKS
1. Nine four Whiskey: Proceed direct Kennedy Warning: Right Engine Fire	1. Radio message presented alone. Misled by one subject.	
2. Caution: Inlet Ice	2. Synthetic voice message presented with radio messages of no interest. Understood by all subjects.	
3. a. Nine four Whiskey: Can proceed on course remain this frequency Warning: Right Engine Fire b. Nine four Whiskey: Can proceed on course remain this frequency Warning: Right Engine Fire c. Nine four Whiskey: Can proceed on course remain this frequency Warning: Right Engine Fire	3. Radio and synthetic voice messages presented as shown. Subjects A, B, C received a. Subject D received b. Subjects E and F received c. Radio message missed by all subjects. Synthetic voice message not understood by three subjects (A, B, E). Synthetic voice message understood by three subjects (C, D, F).	Had to hear call sign, therefore CAW diverted attention and call sign lost from short term memory. Attention diverted from radio call sign - or - short term memory lost by attending to CAW or confusion resulting from trying to attend to both simultaneously caused loss of stimuli.
4. Nine four Whiskey: Proceed direct to Sandy Hook Warning: Reduce Speed	4. Radio and synthetic voice messages presented as shown. Radio message understood by all subjects. Synthetic voice message not understood by one subject (A). Synthetic voice message understood by five subjects (B through F).	
5. Caution: Auto Throttle Disengaged	5. Synthetic voice message presented with radio messages of no interest. Understood by all subjects.	

TABLE 5: ANNOTATED CHART SHOWING DEGREE OF MESSAGE SYNCHRONY: DICHOTIC LISTENING

Degree of message overlap shown in time as follows:



Dichotic:
Two channels presented separately to each ear during simultaneous transmission. When synthetic voice is transmitted, the radio transmitted human voice will be blanked in the ear receiving synthetic voice.

MESSAGES PRESENTED TO SUBJECTS, SHOWING DEGREE OF OVERLAP	COMMENTARY	REMARKS
1. Nine four Whiskey: Traffic off your right side 1 o'clock outlow you 2000 land at Kennedy Warning: Brakes	1. Radio and synthetic voice messages presented as shown. Radio message not understood by one subject (D).	
2. Nine four Whiskey: Left two-two-zero Caution: Rose Wheel Steering Engaged	2. Radio and synthetic voice messages presented as shown. Radio message missed by four subjects (A, B, C, D). Radio message not understood by one subject (F). Radio message understood by one subject (E). Synthetic voice message missed by one subject (E). Synthetic voice message not understood by one subject (A). Synthetic voice message understood by four subjects (B, C, D, F).	Messages are of comparable length, short. When simultaneous, it is possible that demand on attention caused missed message or loss of short term memory item.
3. Nine four Whiskey: Now cleared ... (Fade Out)	3. Radio message presented alone. Radio message not understood by two subjects (D, F). Radio message understood by four subjects (A, B, C, E).	This message not as intelligible as others.
4. Caution: Low Rudder Authority	4. Synthetic voice messages presented with 5. Radio messages of no interest. 5. Understood by all subjects.	
5. Caution: Canopy Unlocked		

TABLE 6: COMPARISONS OF PERFORMANCE BY CATEGORY OF MESSAGE SIMULTANEITY

A. Radio Messages by category of simultaneity. Within each listening method, the radio messages of interest fell into three categories:	DIOTIC		DIOTIC/DICHOTIC		DICHOTIC	
	SCORE	PERCENT	SCORE	PERCENT	SCORE	PERCENT
1. Call sign obscured by synthetic voice message	0/60	0%	0/30	0%	15/60	25%
2. Call sign clear of synthetic voice message	35/60	58.3%	0/30	0%	55/60	91.6%
3. Radio message clear of synthetic voice message (no overlap/no competition)	60/60	100%	110/120	91.6%	50/60	83.3%
TOTALS	95/180	52.7%	110/180	61.1%	120/180	66.6%

*Note that radio remains in both ears when not in synchrony with synthetic voice

B. Synthetic voice messages by category of simultaneity Within each listening method, the synthetic voice caution and warning (C & W) messages fell into two categories:	DIOTIC		DIOTIC/DICHOTIC		DICHOTIC	
	SCORE	PERCENT	SCORE	PERCENT	SCORE	PERCENT
1. C & W simultaneous with radio message of interest	120/120	100%	45/60	75%	90/120	75%
2. C & W simultaneous with radio chatter or with no overlap of radio message of interest	115/120	95.8%	175/180	97.2%	120/120	100%
TOTALS	235/240	97.9%	220/240	91.6%	210/240	87.5%

TABLE 7: COMPARISONS OF RADIO MESSAGE PERCEPTION BY
CATEGORY OF CALL SIGN OBFUSCATION

	DEGREE OF CALL SIGN OBFUSCATION			TOTALS
	CLEAR	PARTIAL	OBSCURED	
NO. MESSAGES MISSED	2	6	13.5	21.5
NO. MESSAGES UNDERSTOOD	22	9	1.5	32.5

E. Understanding Radio Messages With Unobstructed Call Signs

A further examination of Tables 3, 4 and 5 reveals that during simultaneous reception, the synthetic voice message affected the subject's perception of the radio message differently depending upon the relative onset of each message.

When both messages started simultaneously, the message with greater audibility (synthetic voice) obscured the radio message call sign. Therefore, even though the subject may have perceived the message following the call sign, he did not know that it was directed to him. He did not pay attention and the message was lost.

When the synthetic voice message started after the radio call sign, most subjects were able to perceive both messages. Most of these subjects were able to understand the synthetic voice message, while some also were able to understand the radio message. Apparently, those subjects who exhibited this dual understanding were able to switch attention quickly from one message to another. Also, since they could not perceive the radio message words at the same time as they attended to the synthetic voice, it appears likely that the meaning of the lost words were reconstructed from the context of the message portion that was understood. (Discussion during debriefing tends to support this thesis).

A questionnaire eliciting subjective evaluations and comments was completed by each subject immediately following the finish of his test runs. A copy of each completed questionnaire is included in the Appendix (pages 33 to 44). In all cases the quality of both radio and synthetic voices used in this study were rated satisfactory or better.

XII CONCLUSIONS

This preliminary study has permitted insight into four basic events:

1. Key radio messages can be heard and understood when presented simultaneously with synthetic female voice caution and warning messages.
2. It is essential that the subject perceive his call sign if he is to hear and understand the radio message.
3. Virtually all synthetic female voice caution and warning messages can be heard and understood, whether or not any radio messages are present.
4. There are differences in the ability of a subject to hear and understand radio messages as a function of different methods of presenting competing synthetic female voice caution and warning messages.

The results of this study tend to support the belief that synthetic voice messages (in this case, female voice) provide an effective means of presenting alerting messages and data to a pilot.

Additionally, it should not be necessary to mute radio messages to a level below the pilot's perception as is done in at least two aircraft today, thereby ensuring the loss of radio messages during the transmission of synthetic voice messages.

Further, it appears that some radio messages may be understood even though a part of the message may be lost to the pilot's understanding. Apparently, the sense of the message is reconstructed from the context of the message portion that is understood.

Future studies are planned to investigate further these findings. It is intended to include the investigation of other types of synthetically generated voices, such as natural male and robotic or neuter. Particular attention will be paid to reaffirming the efficacy of the dichotic listening method.

APPENDIX

TEST SUBJECT INSTRUCTIONS

This experiment in which you are participating is designed to evaluate cockpit communications and aircraft attitude control. Your function is that of an experienced pilot flying your aircraft and responding to pertinent communications.

You will be seated in front of a large CRT and you will wear headphones. A microphone will be placed in front of you. A forcestick control will be adjacent to the CRT. It may be placed wherever you wish for your comfort.

A graphic representation of an attitude control instrument (containing a horizon line and aircraft symbol) will be presented on the CRT. During the experiment your job will be to maintain aircraft attitude by use of the forcestick control. You will be controlling the aircraft symbol movement. In addition, the words ELEV and ANGLE will appear in the upper corners of the CRT. This additional information will appear whenever you are not straight and level.

Two types of comm messages will require your responses:

1. Whenever you hear a caution or warning message, you are to repeat it aloud.
2. Whenever you hear a message with the call-sign "94 WHISKEY", you are to repeat it aloud.

Should you hear a C&W message and a radio message at about the same time, you are to repeat them aloud. YOU SHOULD DELAY YOUR VERBAL RESPONSE TO ENSURE HEARING THE ENTIRE MESSAGE(S). In the event you hear a message(s) as described above, but do not catch all the words, state aloud what you think the message was about. You cannot request a repeat of the message.

Remember, you must maintain aircraft attitude control at all times, otherwise you risk departure from normal flight.

Before donning headset, check for right/left orientation.

TEST SUBJECT RATING SHEET

NAME: _____

Please check the box adjacent to your selection for each statement.

1. Rate the quality of synthetic voice in this study.

☐ Extremely Poor ☐ Poor ☐ Satisfactory ☐ Good ☐ Excellent

2. Rate your ability to perceive the synthetic voice messages.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☐ Good ☐ Excellent

3. Rate your ability to understand the synthetic voice messages.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☐ Good ☐ Excellent

4. Rate the quality of radio voice in the cockpit during actual flight.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☐ Good ☐ Excellent

5. Rate the quality of radio voice in this study.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☐ Good ☐ Excellent

6. Rate your ability to perceive your radio call sign.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☐ Good ☐ Excellent

7. Rate your ability to understand the radio message following your call sign.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☐ Good ☐ Excellent

TEST SUBJECT RATING SHEET (Cont'd.)

8. Did you encounter any problems in attending to and/or understanding simultaneous messages (synthetic and radio voice)?

☐ Yes

If your answer is Yes, please elaborate:

☐ No

Use the space below for providing additional comments and/or evaluations.

TEST SUBJECT RATING SHEET

NAME: _____

A

Please check the box adjacent to your selection for each statement.

1. Rate the quality of synthetic voice in this study.

☐ Extremely Poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

2. Rate your ability to perceive the synthetic voice messages.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

3. Rate your ability to understand the synthetic voice messages.

☐ Extremely poor ☒ Poor ☐ Satisfactory ☐ Good ☐ Excellent

4. Rate the quality of radio voice in the cockpit during actual flight.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

5. Rate the quality of radio voice in this study.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent

6. Rate your ability to perceive your radio call sign.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent

7. Rate your ability to understand the radio message following your call sign.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

TEST SUBJECT RATING SHEET (Cont'd.)

8. Did you encounter any problems in attending to and/or understanding simultaneous messages (synthetic and radio voice)?

☒ Yes

If your answer is Yes, please elaborate:

☐ No

They seem to cancel each other.

Use the space below for providing additional comments and/or evaluations.

Preparation for & explanation of test procedures are excellent.

TEST SUBJECT RATING SHEET

NAME: _____

B

Please check the box adjacent to your selection for each statement.

1. Rate the quality of synthetic voice in this study.

☐ Extremely Poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

2. Rate your ability to perceive the synthetic voice messages.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☐ Good ☒ Excellent

3. Rate your ability to understand the synthetic voice messages.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent

4. Rate the quality of radio voice in the cockpit during actual flight.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

5. Rate the quality of radio voice in this study.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent

6. Rate your ability to perceive your radio call sign.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☐ Good ☒ Excellent

7. Rate your ability to understand the radio message following your call sign.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent

TEST SUBJECT RATING SHEET (Cont'd.)

8. Did you encounter any problems in attending to and/or understanding simultaneous messages (synthetic and radio voice)?

☐ Yes

☒ No

If your answer is Yes, please elaborate:

Use the space below for providing additional comments and/or evaluations.

Warning could be repeated
if more two words
Some of or in one case the
warning such as Brakes
was unexpected with air traffic
clearance.

Fingers tended to tinge on
small flight control

TEST SUBJECT RATING SHEET

NAME: _____

C

Please check the box adjacent to your selection for each statement.

1. Rate the quality of synthetic voice in this study.
☐ Extremely Poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent
2. Rate your ability to perceive the synthetic voice messages.
☐ Extremely poor ☐ Poor ☐ Satisfactory ☐ Good ☒ Excellent
3. Rate your ability to understand the synthetic voice messages.
☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent
4. Rate the quality of radio voice in the cockpit during actual flight.
☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent
5. Rate the quality of radio voice in this study.
☐ Extremely poor ☐ Poor ☒ Satisfactory^① ☐ Good ☐ Excellent
6. Rate your ability to perceive your radio call sign.
☐ Extremely poor ☐ Poor ☒ Satisfactory^① ☐ Good ☐ Excellent
7. Rate your ability to understand the radio message following your call sign.
☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

① THE RADIO VOICE AND CALL SIGNS WERE ON OCCASION MUFFLED OR SLURRED MAKING IT DIFFICULT TO PICK UP - ONCE RECOGNIZED THERE WAS NO PROBLEM WITH THE MESSAGE

TEST SUBJECT RATING SHEET (Cont'd.)

8. Did you encounter any problems in attending to and/or understanding simultaneous messages (synthetic and radio voice)?

☐ Yes

☒ No ②

If your answer is Yes, please elaborate:

Use the space below for providing additional comments and/or evaluations.

② IN THE EVENT OF SIMULTANEOUS MESSAGES THE CAUTION/WARNINGS PREDOMINATED.

TEST SUBJECT RATING SHEET

NAME: _____

D

Please check the box adjacent to your selection for each statement.

1. Rate the quality of synthetic voice in this study.

☐ Extremely Poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

2. Rate your ability to perceive the synthetic voice messages.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent

3. Rate your ability to understand the synthetic voice messages.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

4. Rate the quality of radio voice in the cockpit during actual flight.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

5. Rate the quality of radio voice in this study.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

6. Rate your ability to perceive your radio call sign.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent

7. Rate your ability to understand the radio message following your call sign.

☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent

TEST SUBJECT RATING SHEET (Cont'd.)

8. Did you encounter any problems in attending to and/or understanding simultaneous messages (synthetic and radio voice)?

☒ Yes

If your answer is Yes, please elaborate:

☐ No

SOME MESSAGES FROM THE WARNING SYSTEM WERE
CARBLED AND CN CLIPPED AT THE BEGINNING OF THE MESSAGE.

"RIGHT / LEFT" C4W AMBIGUOUS
(WORD)

C4W — OVERTEMP message - too long?

Use the space below for providing additional comments and/or evaluations.

TEST SUBJECT RATING SHEET

NAME: _____

E

Please check the box adjacent to your selection for each statement.

1. Rate the quality of synthetic voice in this study.

☐ Extremely Poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

2. Rate your ability to perceive the synthetic voice messages.

☐ Extremely poor ☒ Poor ☐ Satisfactory ☐ Good ☐ Excellent

3. Rate your ability to understand the synthetic voice messages.

☐ Extremely poor ☒ Poor ☐ Satisfactory ☐ Good ☐ Excellent

4. Rate the quality of radio voice in the cockpit during actual flight.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

5. Rate the quality of radio voice in this study.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

6. Rate your ability to perceive your radio call sign.

☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent

7. Rate your ability to understand the radio message following your call sign.

☐ Extremely poor ☒ Poor ☐ Satisfactory ☐ Good ☐ Excellent

TEST SUBJECT RATING SHEET (Cont'd.)

8. Did you encounter any problems in attending to and/or understanding simultaneous messages (synthetic and radio voice)?

☒ Yes

If your answer is Yes, please elaborate:

☐ No

CAUTIONS & WARNINGS WERE IN MONOTONE
SIMILAR TO ATC. SHOULD BE ACCENTED
(LOUDER, HIGHER PITCH FOR EXAMPLE)

Use the space below for providing additional comments and/or evaluations.

TEST SUBJECT RATING SHEET

NAME: _____

F

Please check the box adjacent to your selection for each statement.

1. Rate the quality of synthetic voice in this study.
☐ Extremely Poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent
2. Rate your ability to perceive the synthetic voice messages.
☐ Extremely poor ☐ Poor ☐ Satisfactory ☒ Good ☐ Excellent
3. Rate your ability to understand the synthetic voice messages.
☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent
4. Rate the quality of radio voice in the cockpit during actual flight.
☐ Extremely poor ☒ Poor ☐ Satisfactory ☐ Good ☐ Excellent
5. Rate the quality of radio voice in this study.
☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent
6. Rate your ability to perceive your radio call sign.
☐ Extremely poor ☐ Poor ☒ Satisfactory ☐ Good ☐ Excellent
7. Rate your ability to understand the radio message following your call sign.
☐ Extremely poor ☒ Poor ☐ Satisfactory ☐ Good ☐ Excellent

TEST SUBJECT RATING SHEET (Cont'd.)

8. Did you encounter any problems in attending to and/or understanding simultaneous messages (synthetic and radio voice)?

☐ Yes

☒ No

If your answer is Yes, please elaborate:

Use the space below for providing additional comments and/or evaluations.

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